COLLECTIVITY IN SMALL QCD SYSTEMS

Theodore Koblesky

For the PHENIX Collaboration

Boulder

CIPANP 2015

PHENIX

OVERVIEW

- Collectivity
- Measurements
    - d+Au @ 200 GeV
    - ^{3}He+Au @ 200 GeV
- Simulations/Calculations
- Comparison to data
- Summary

WHAT IS COLLECTIVITY

Many discrete structures interacting together to form a whole

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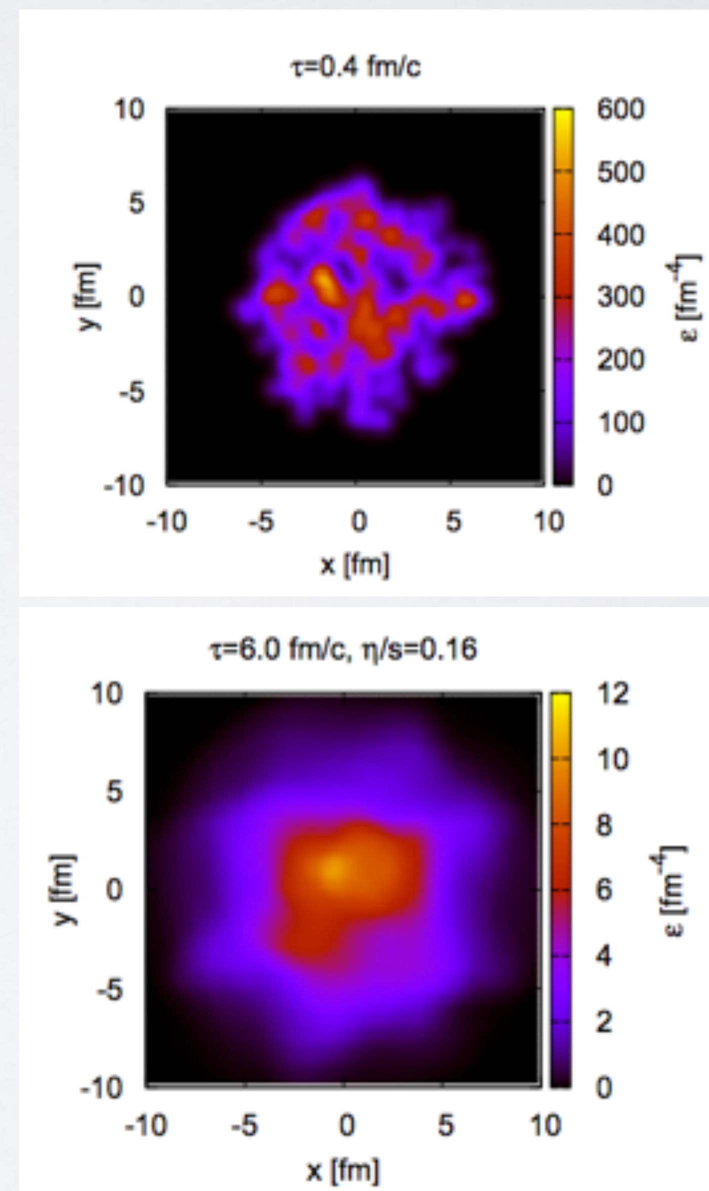

Schenke arXiv:1009.3244

What it means in Heavy Ion Physics

- Nearly all particles behaving the same way
- A medium is formed that can be described as a locally equilibrated system evolving hydrodynamically instead of group of individually interactions constituents.

MEASURING COLLECTIVITY

When many particles are behaving in a similar way, information on the **initial conditions** will be carried through the medium evolution

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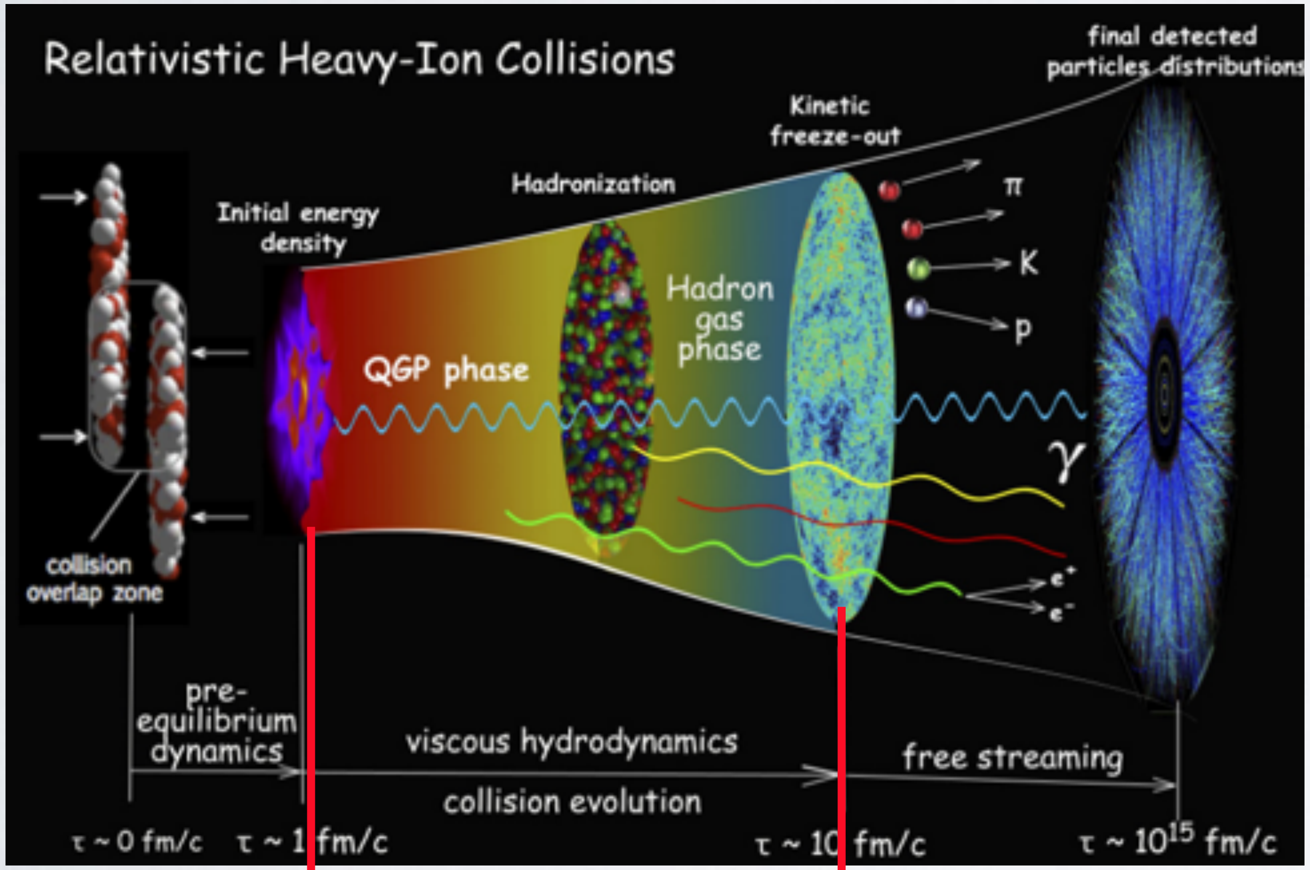
Measuring Collectivity in Heavy Ion Collisions



The Collectivity Phase

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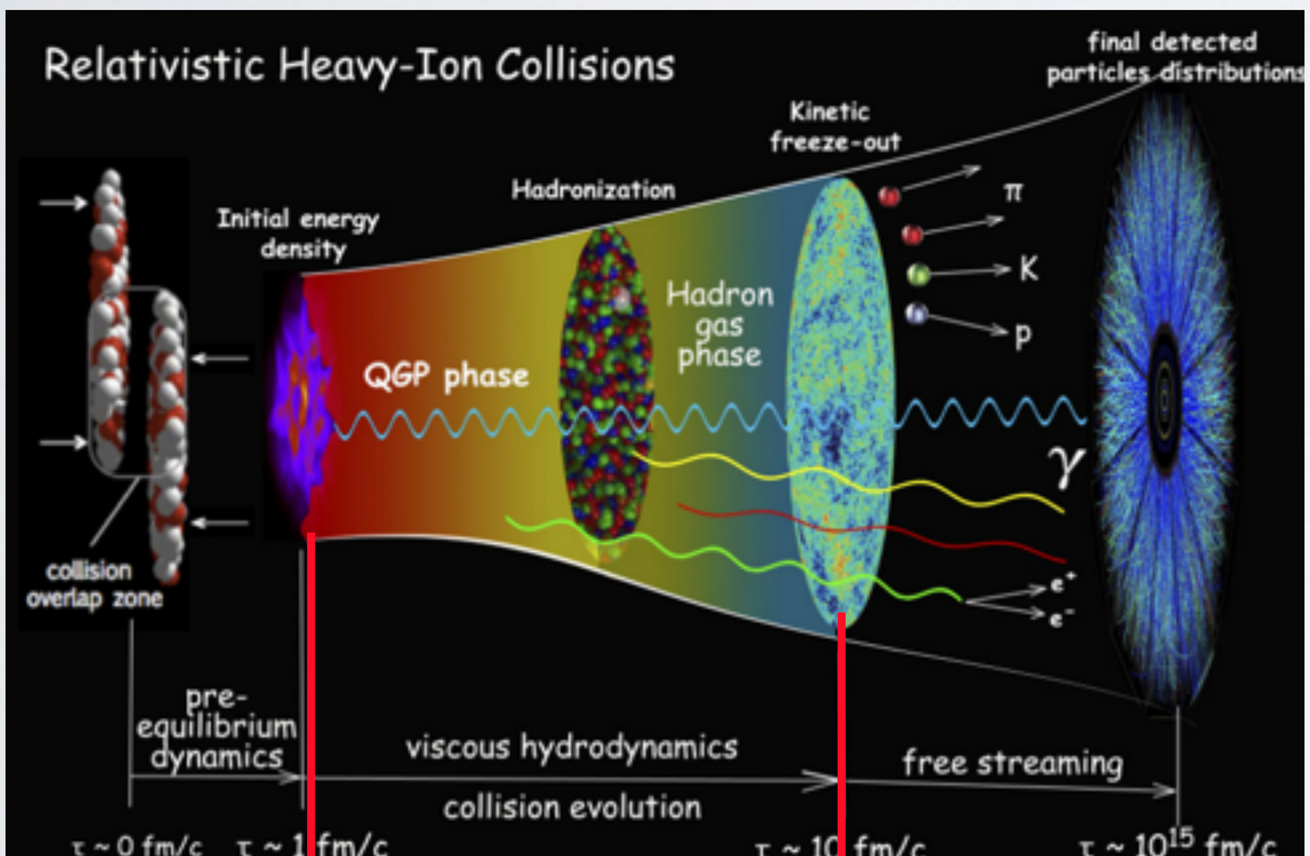
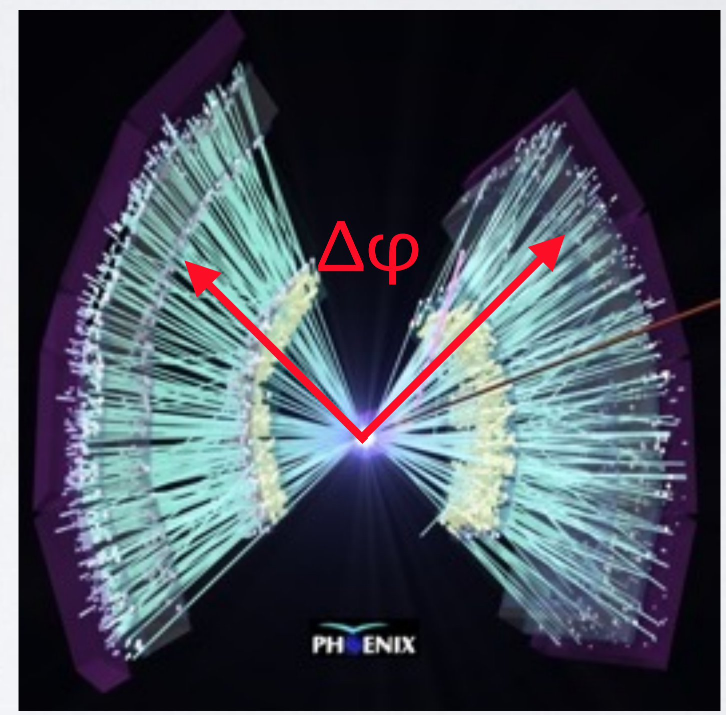
Measuring Collectivity in Heavy Ion Collisions



The Collectivity Phase



In the angular distribution of the spray of particles, there should be **long range angular correlations**.

AZIMUTHAL ANISOTROPY

Find the $\Delta\varphi$ and the $\Delta\eta$ (the difference in the **azimuth** and the **pseudorapidity**) from each pair of particles measured from the collision

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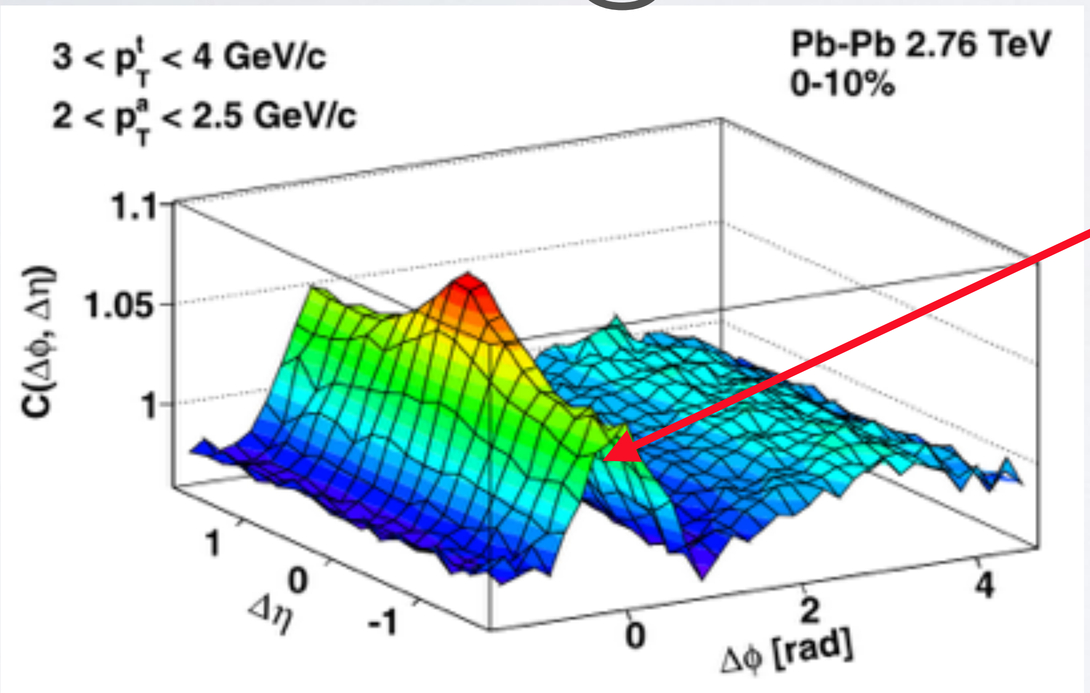
Alice Pb+Pb @ 2.76 TeV

Near Side Ridge



Physics Letters B 708 (2012) 249–264

The detector acceptance must be subtracted out.

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Find the Δφ and the Δη (the difference in the **azimuth** and the **pseudorapidity**) from each pair of particles measured from the collision

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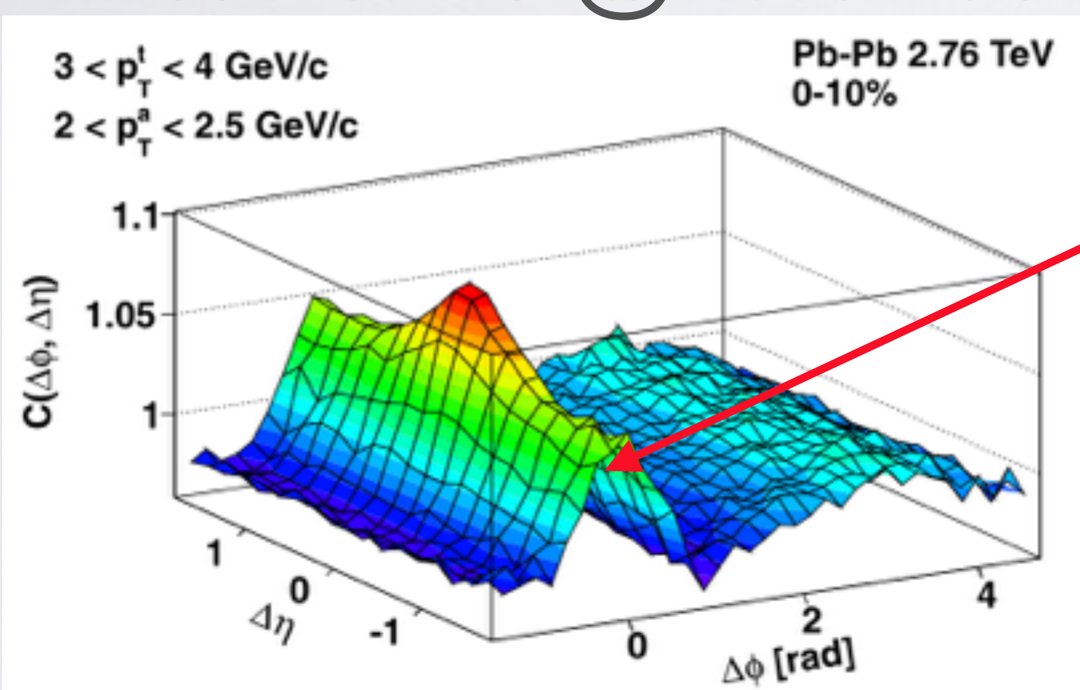

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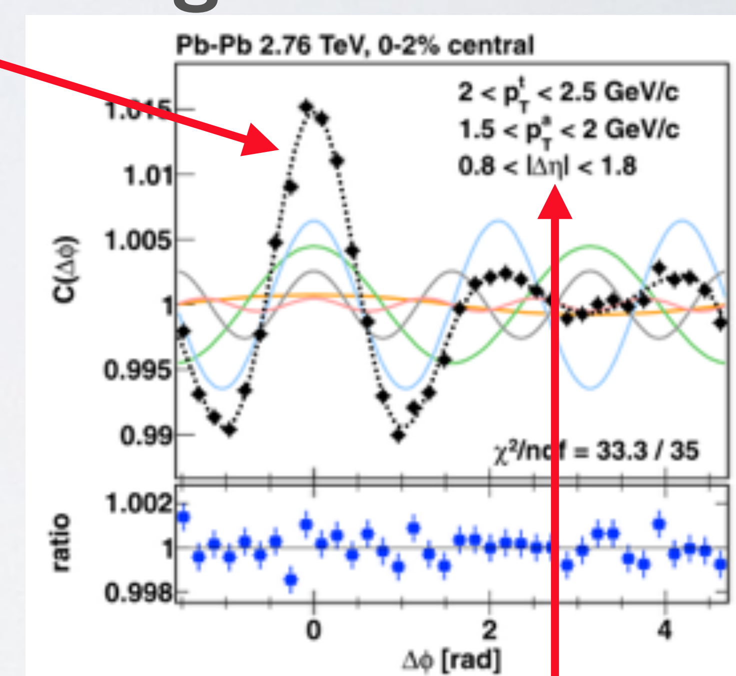
Near Side Ridge

Fourier Transformation



Cut away from the jet peak at $\Delta\eta = 0$

THE SMOKING GUN OF COLLECTIVITY

v_N are Flow Coefficients

$$\frac{dN}{d\phi} \propto 1 + \sum_{n=1} 2\, v_n \cos(n[\phi - \Psi_n]),$$

$$v_n = \langle \cos(n[\phi - \Psi_n]) \rangle \,, n = 1, 2, 3, \ldots$$

Ψ_N is the generalized participant Event Plane

arXiv:1105.3928

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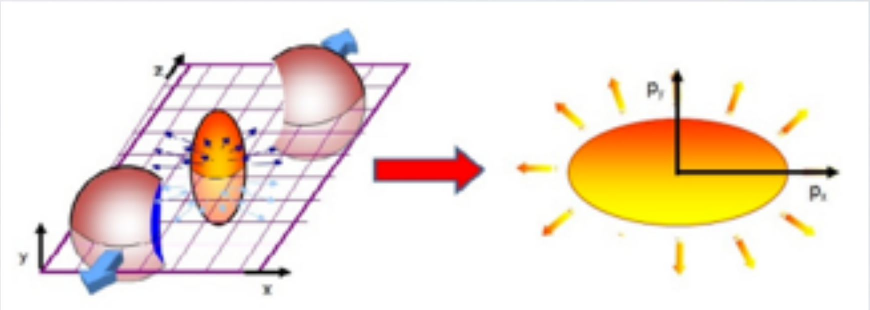
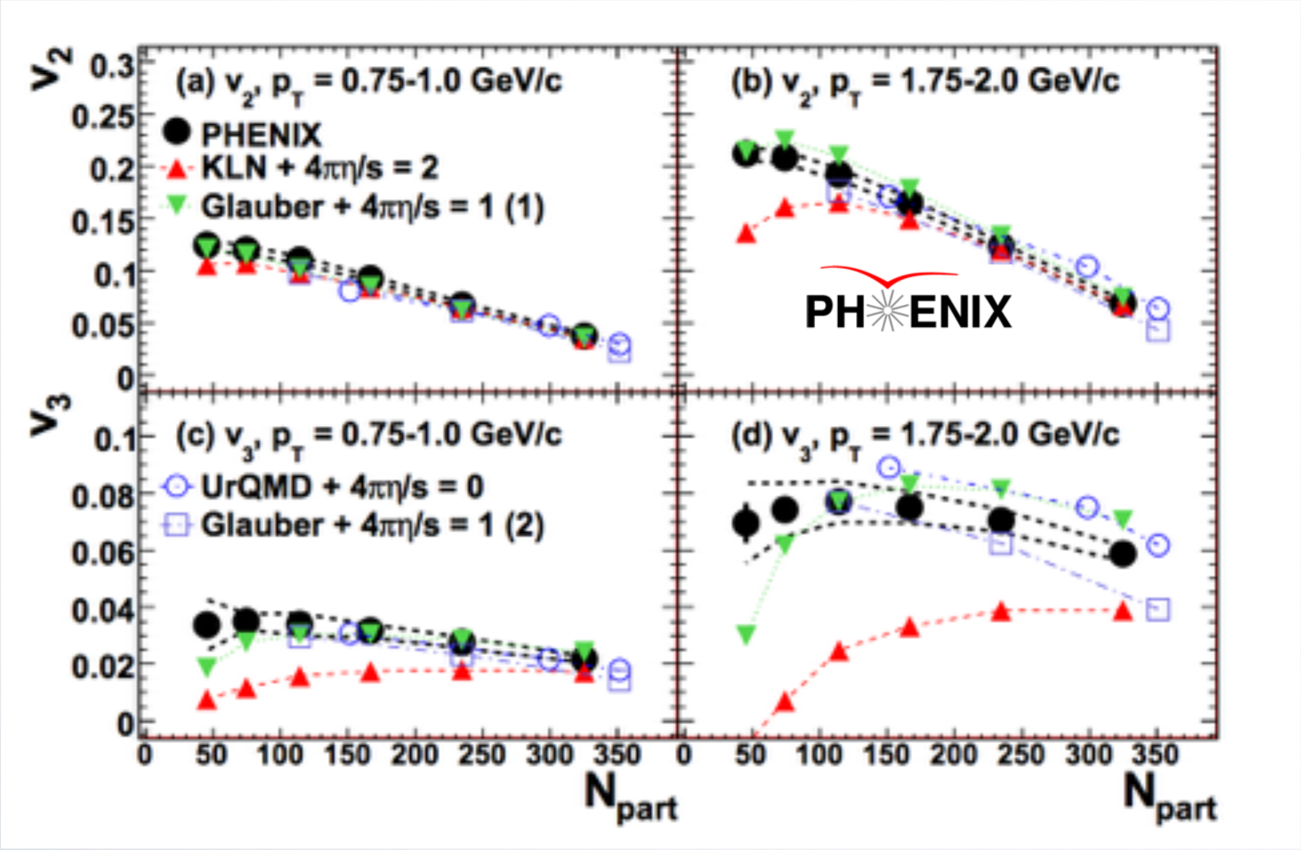


Au+Au @ 200 GeV



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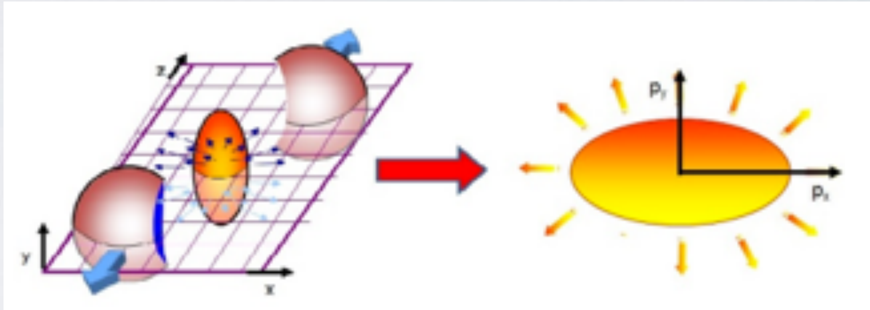
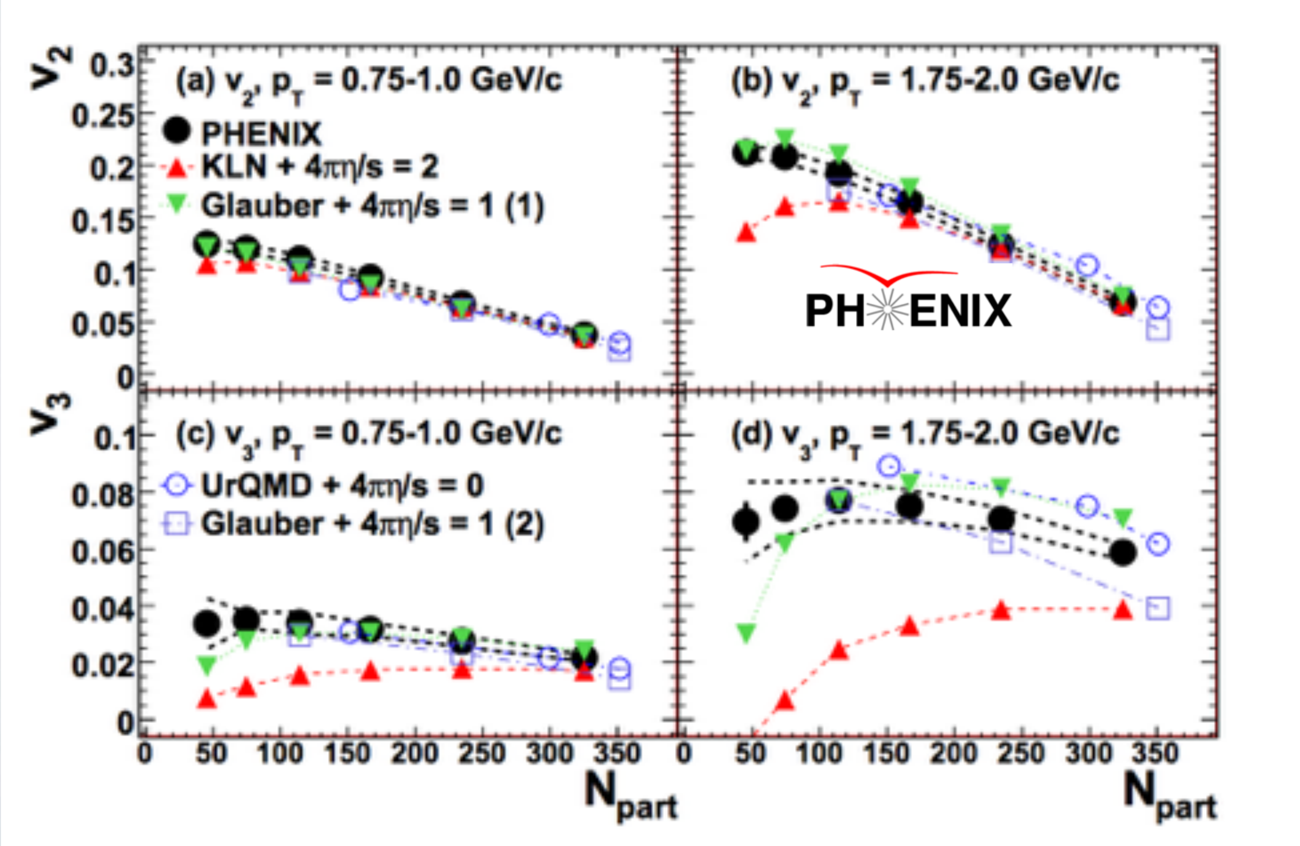
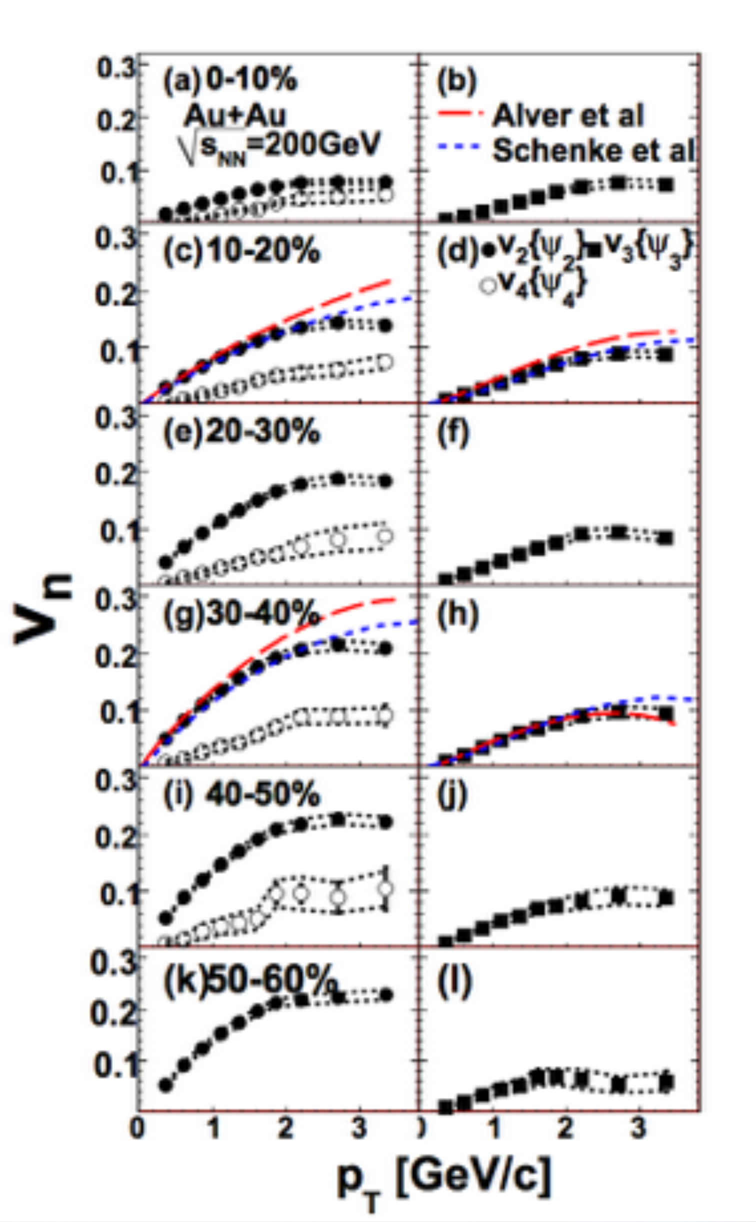


Glauber + Relativistic Viscous Hydro best explain the data

Au+Au @ 200 GeV





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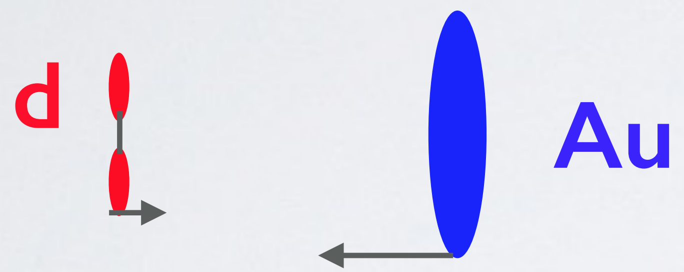
D+AU CORRELATION

d+Au was thought of as the **control test** to measure cold nuclear matter effects.



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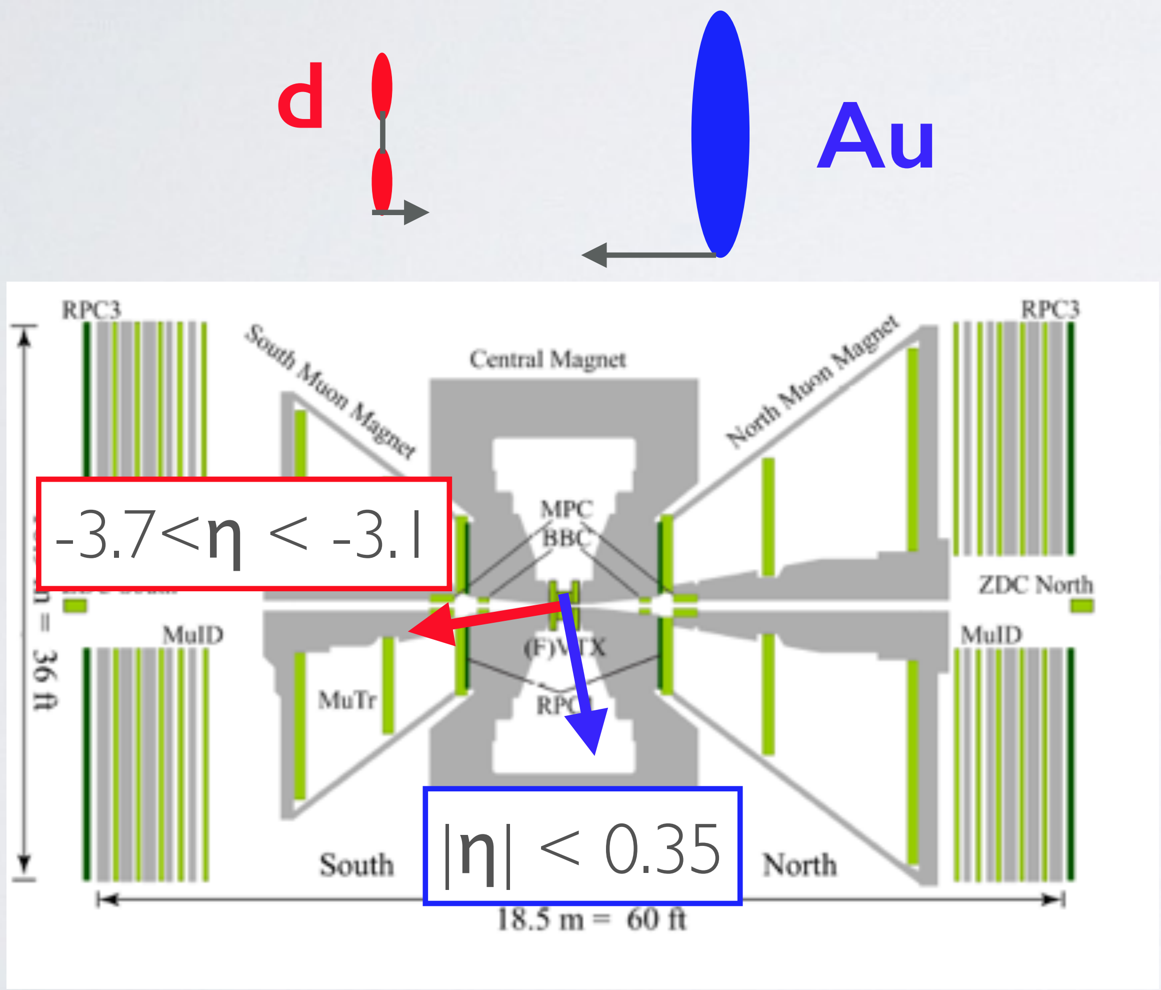

$|\Delta\eta| > 2.75$

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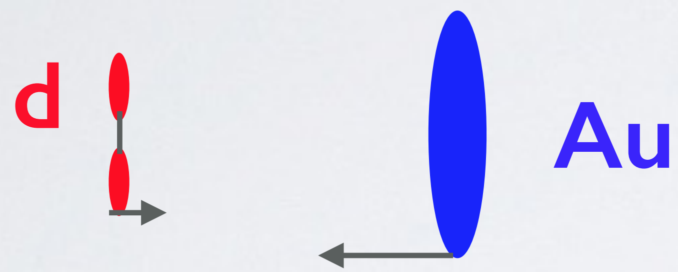
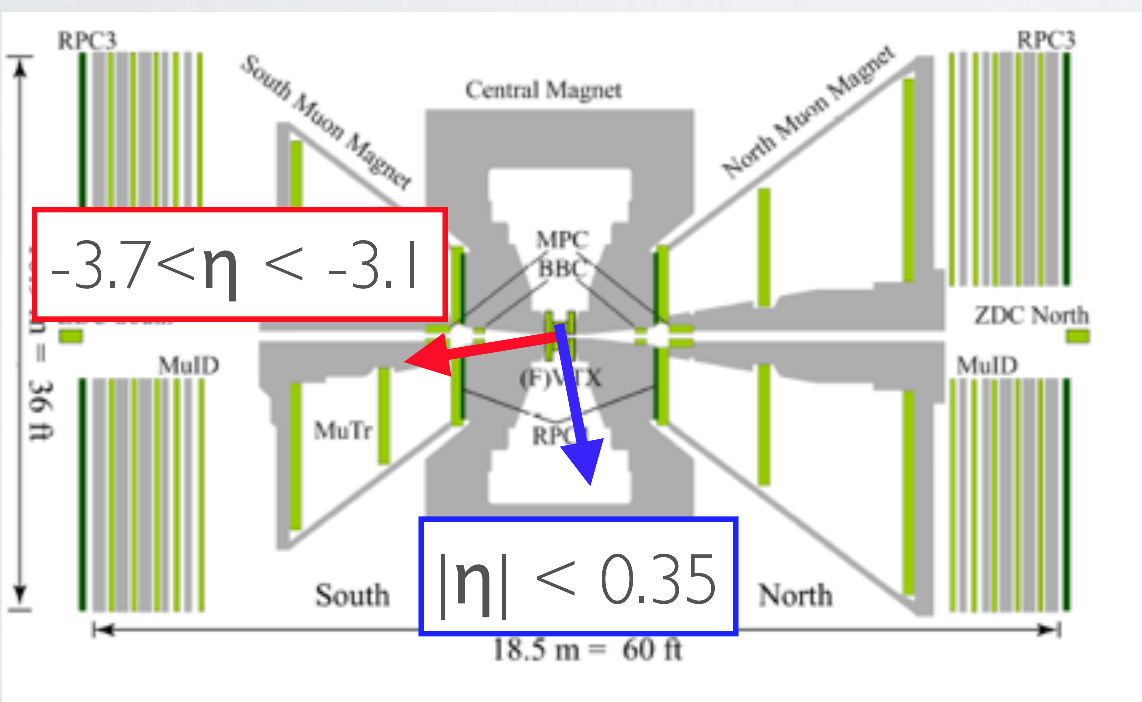
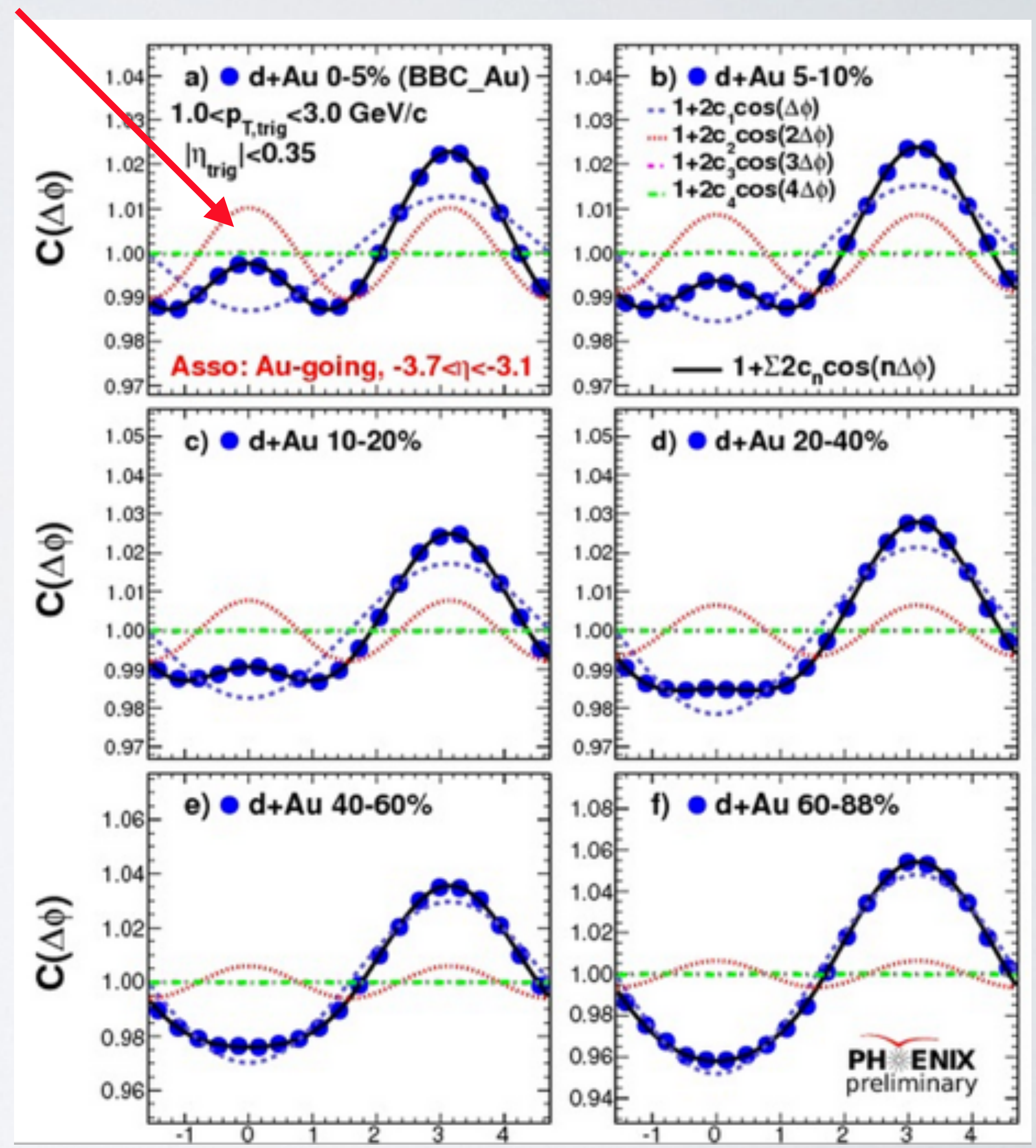




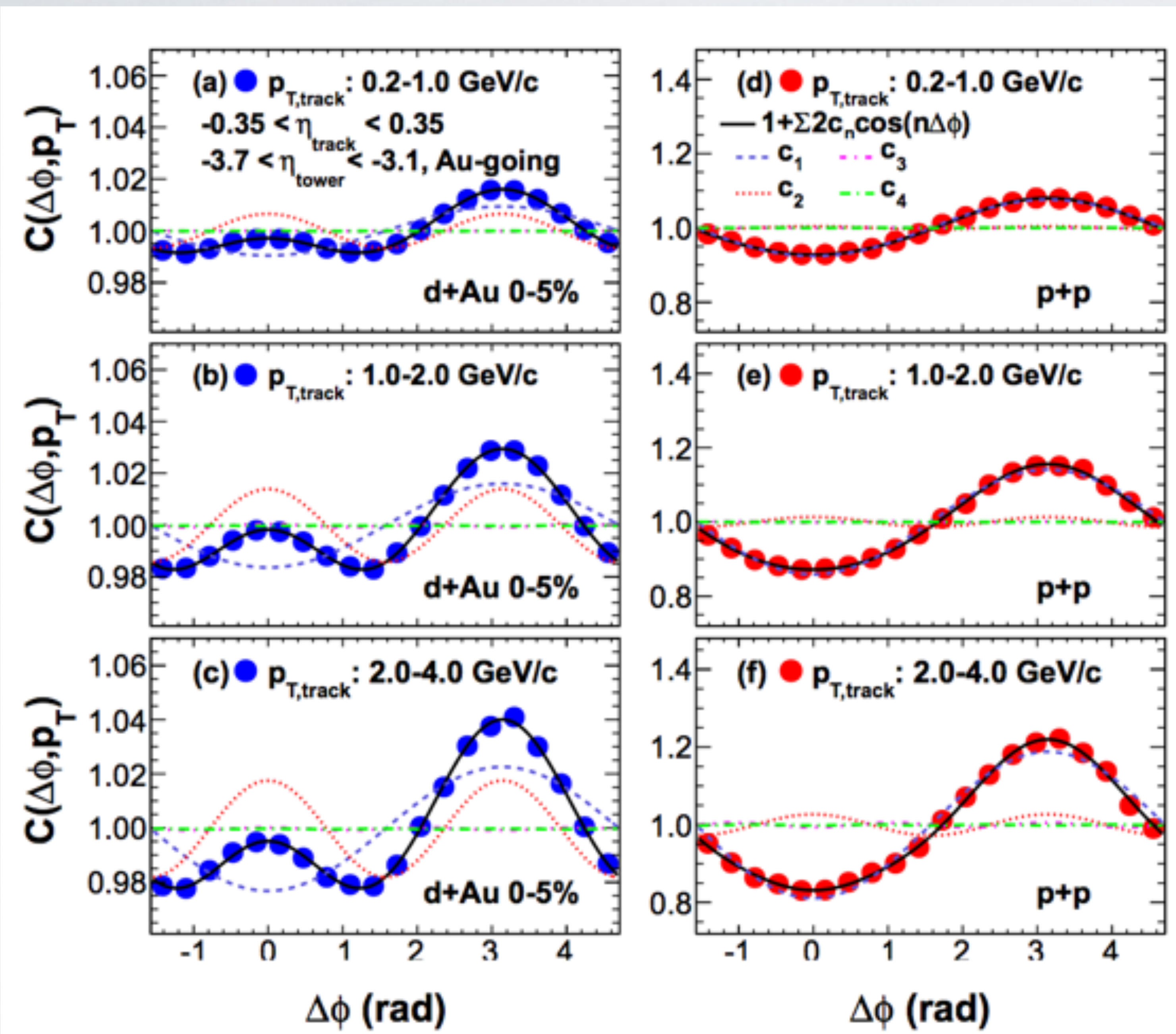
|Δη| > 2.75

Nearside Ridge **d+Au @ 200 GeV**



D+AU P+P COMPARISON

d+Au 0%-5% Central **p+p Minimum Bias**



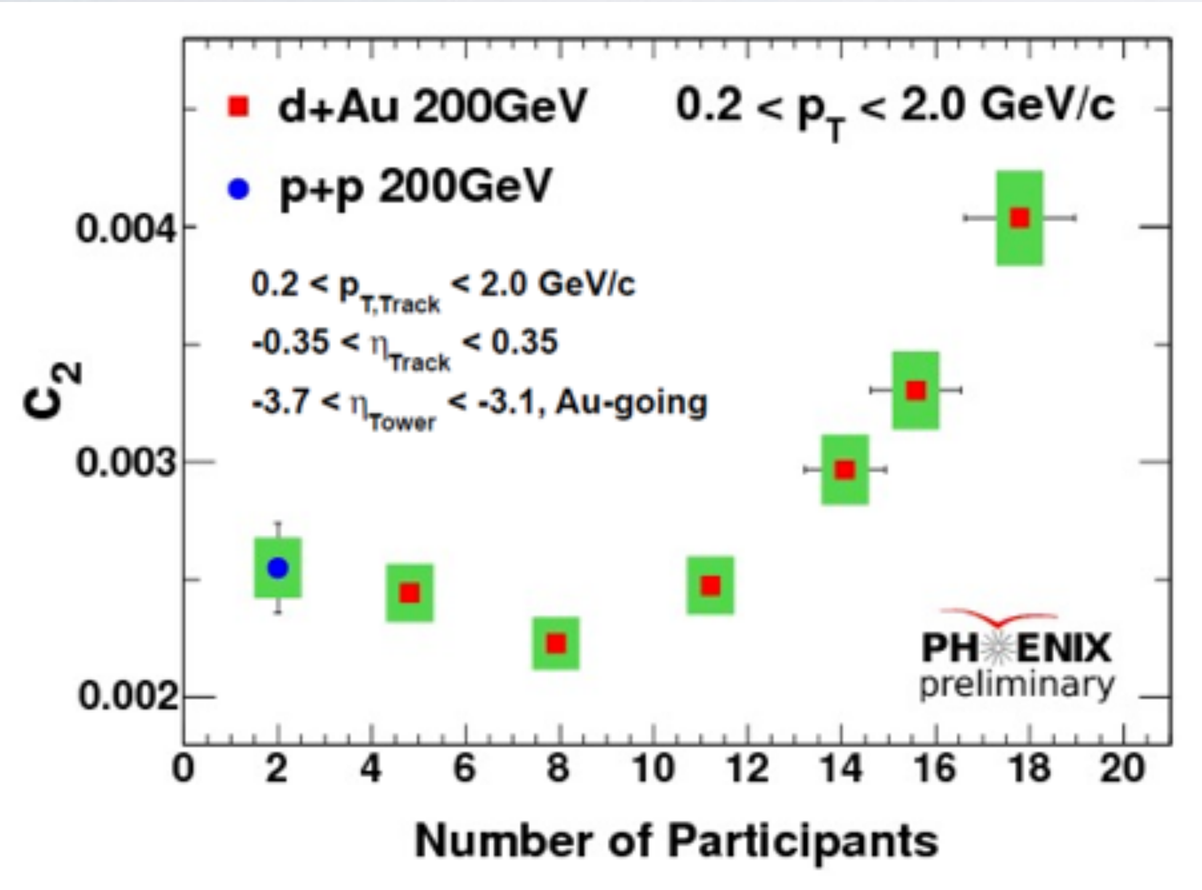
Phys. Rev. Lett. 114, 192301 (2015)

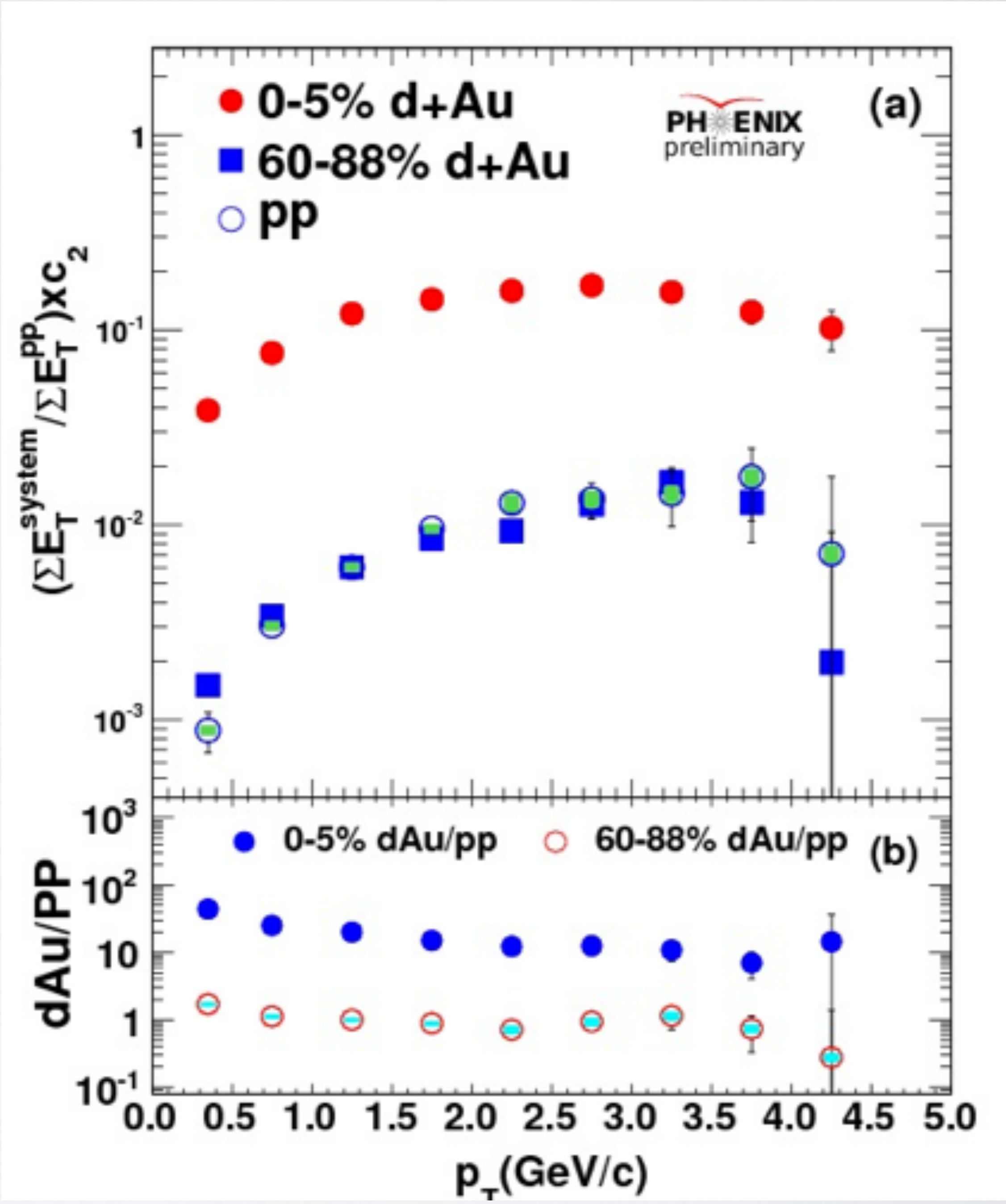
arXiv:1404.7461

- The shape of the **p+p** distribution is mostly described by $\mathbf{c_1}$.
- **p+p** collisions are thought to be dominated by elementary processes such as dijets.
- **p+p** collisions can help estimate the amount of non-flow present in the **d+Au** distribution.

D+AU MOMENTS

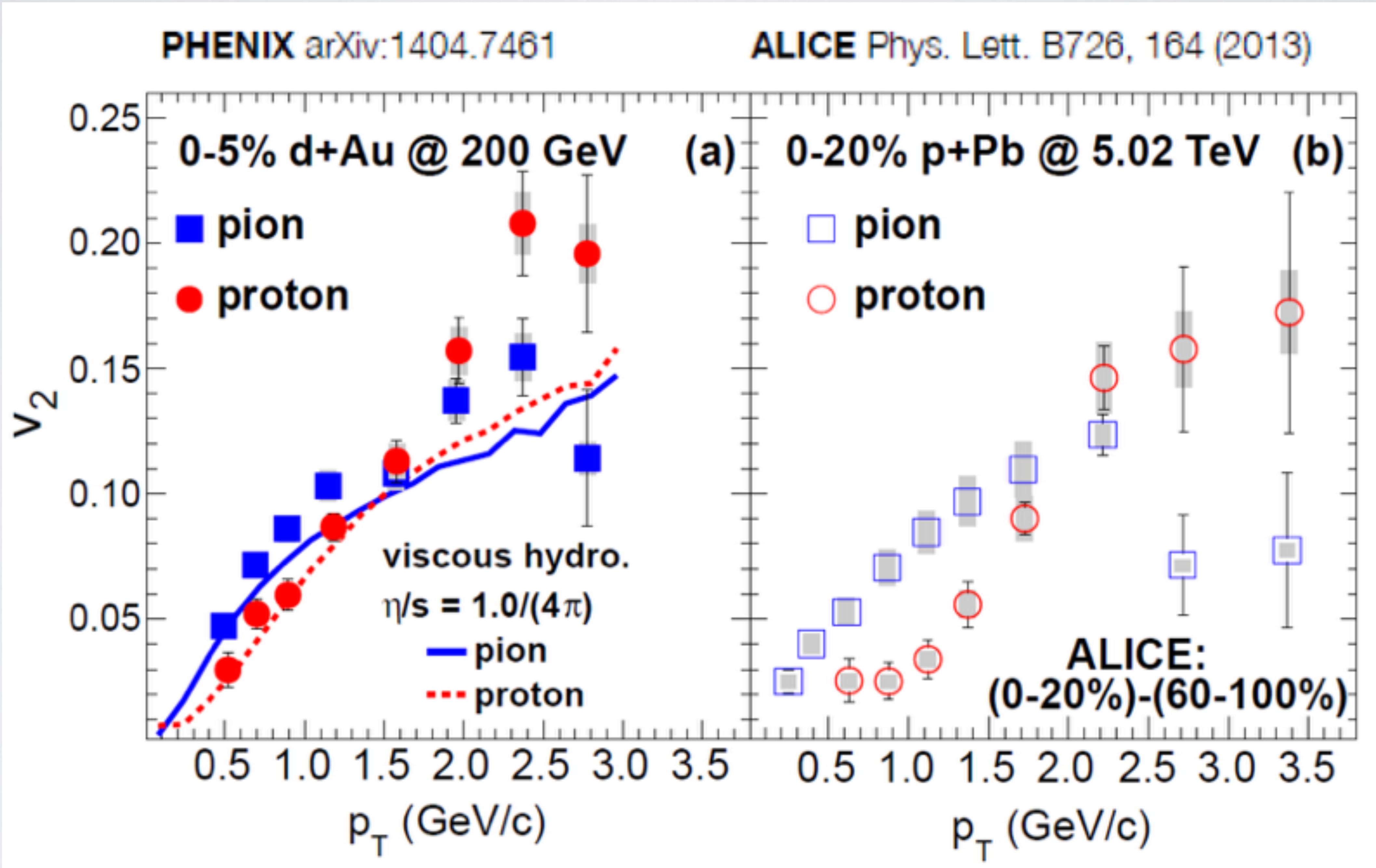
Peripheral **d+Au** behaves very much like **p+p** minimum bias.





Dilution factor

MASS ORDERING IN D+AU AND P+PB

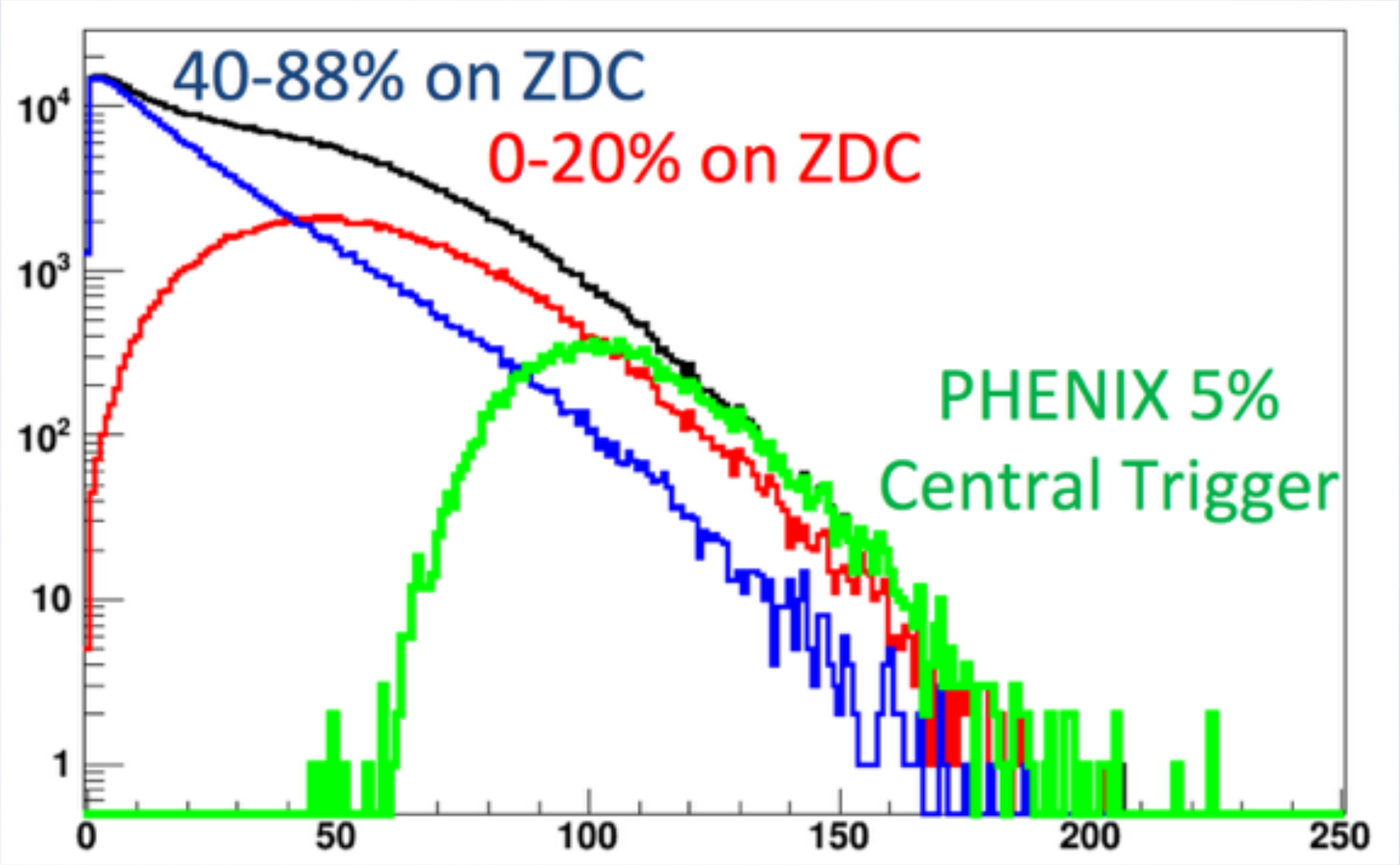


The larger v_2 of the lighter **pion** compared to the heavier **proton** consistent with hydrodynamic flow calculation.

^{3}HE+AU HIGH MULTIPLICITY TRIGGER

A **high multiplicity trigger** is vital to obtain enough events with collectivity.

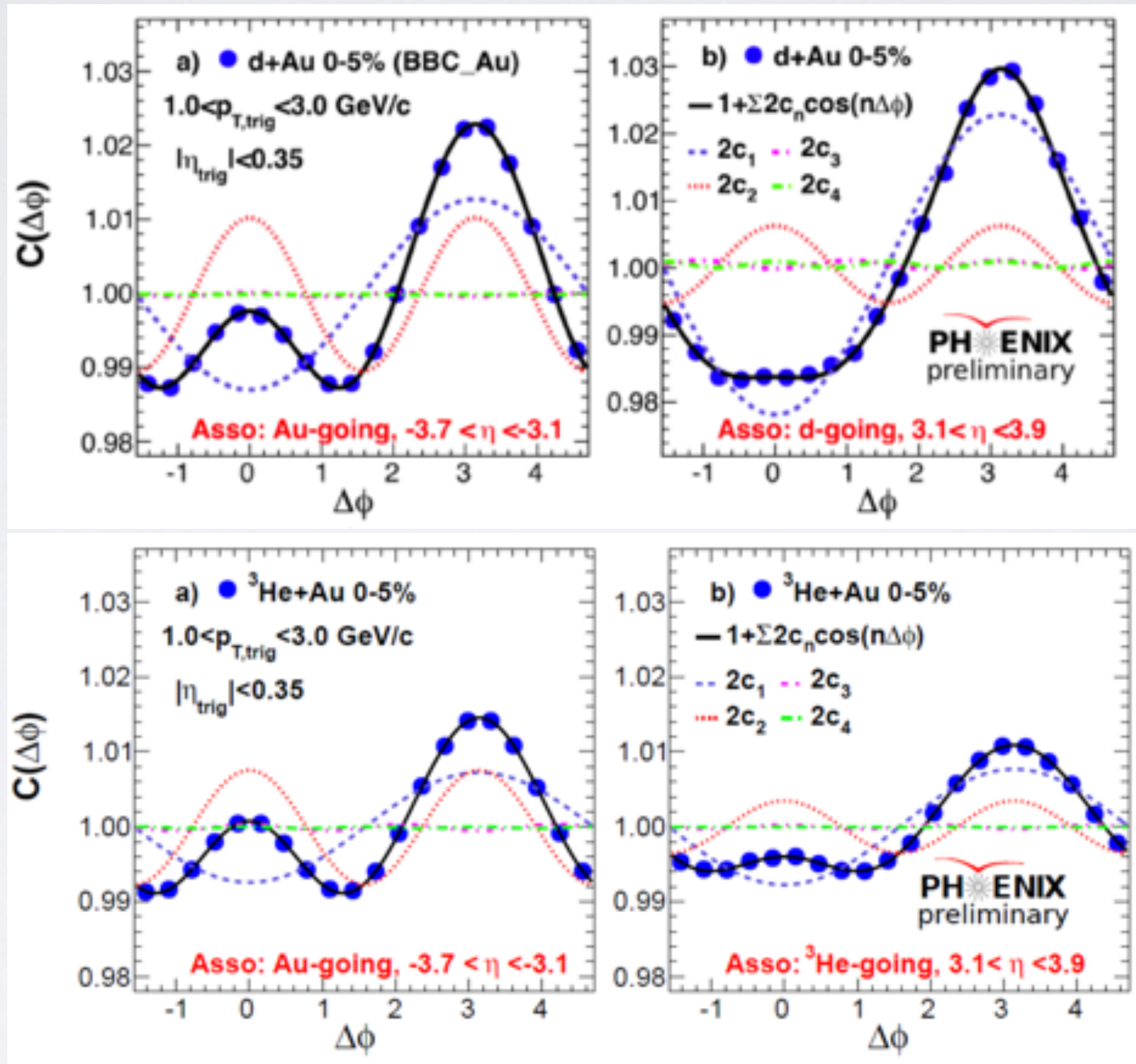
A **7 times gain** in statistics compared to typical minimum bias trigger



BBC Charge (Au going side)

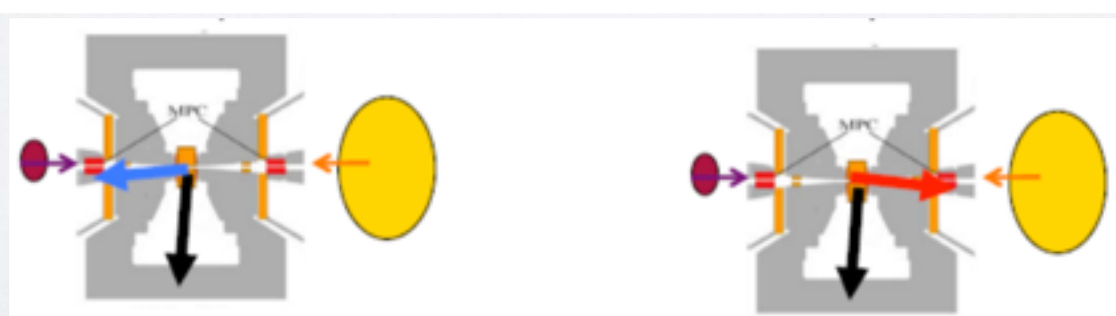
CORRELATION COMPARISON

Au-Going **d/³He-Going**



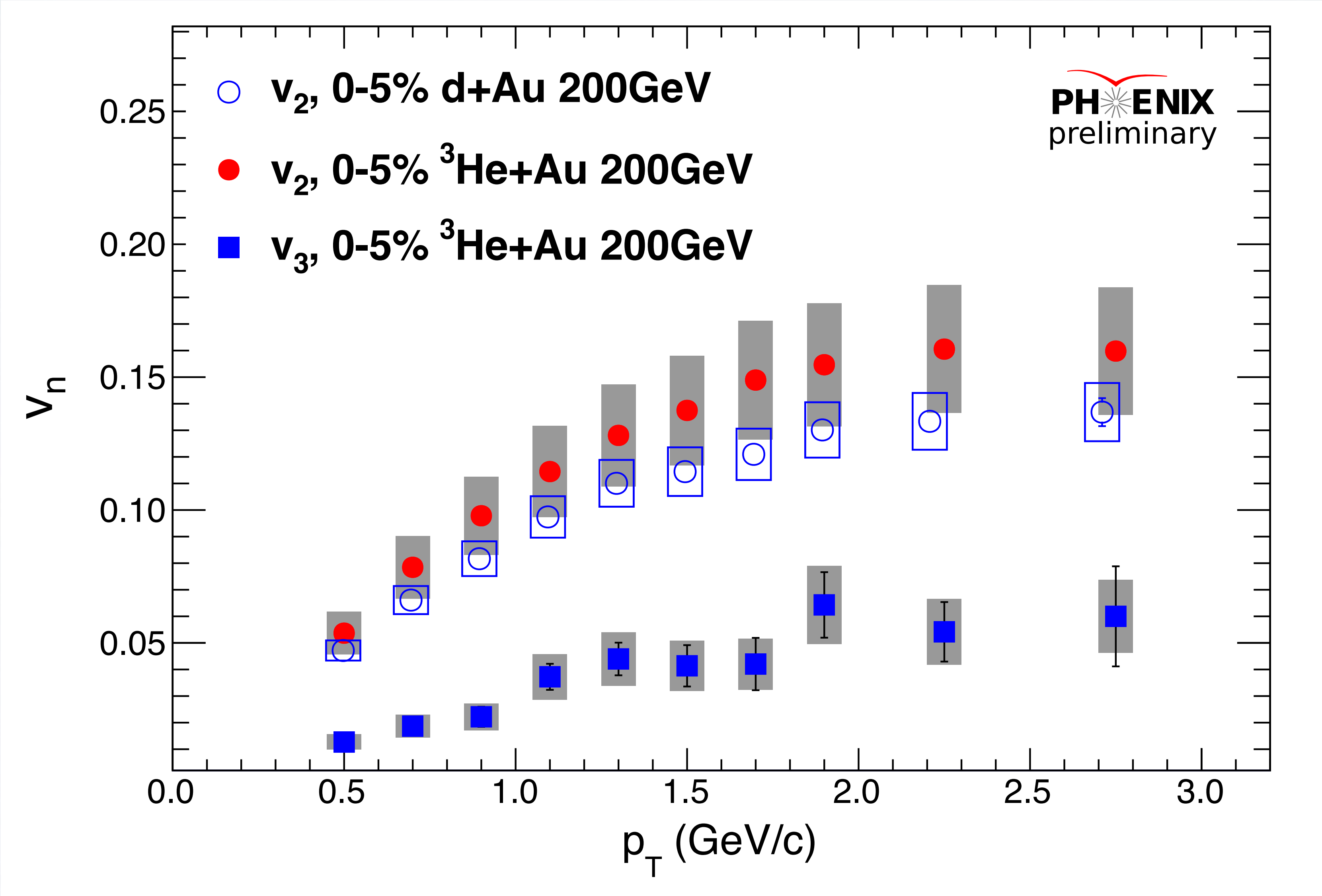
The nearside ridge disappears for the d-going side of **d+Au.**

The nearside ridge is visible for both sides of **^{3}He+Au**.



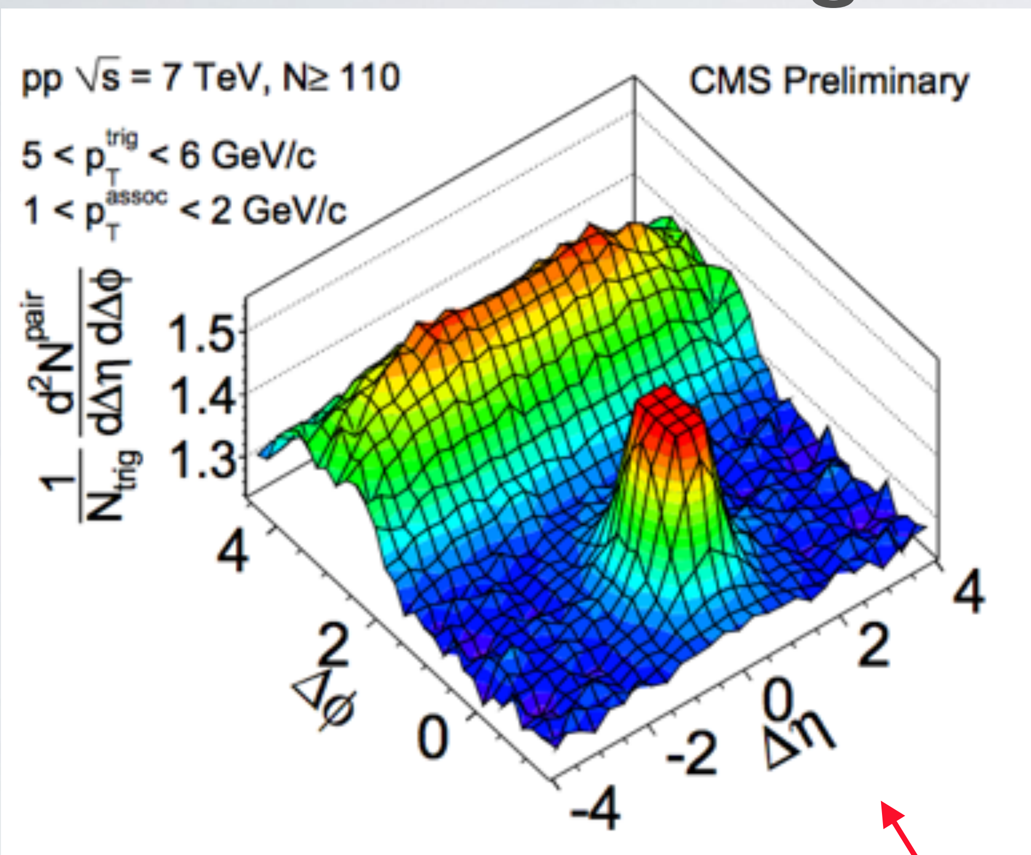
^{3}HE+AU FLOW MOMENTS

- The v_2 is comparable for both systems.
- ^{3}He+Au's natural initial conditions and fluctuations produce a substantial v_3.

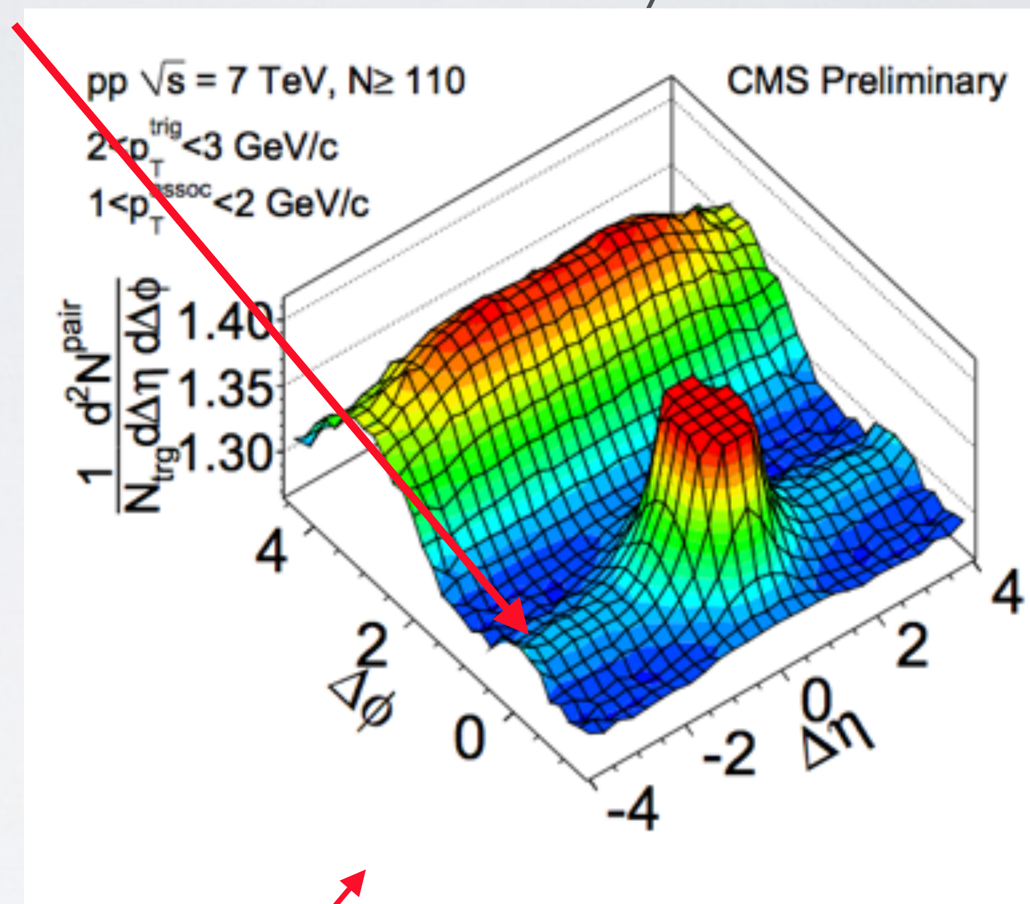


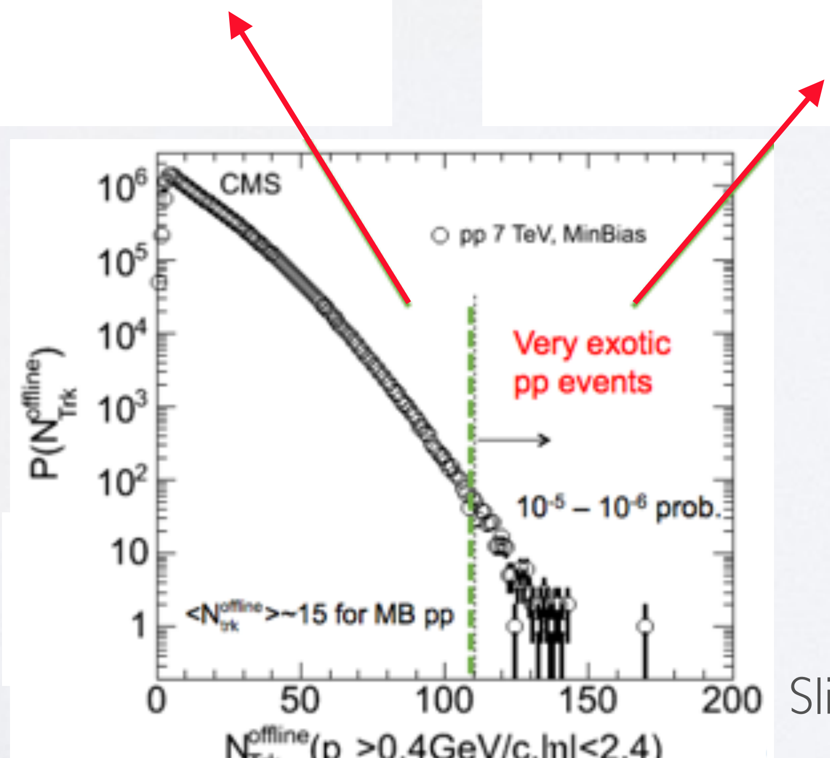
COLLECTIVITY IN P+P COLLISIONS?

Nearside Ridge: evidence of collectivity?



arXiv:1107.2196

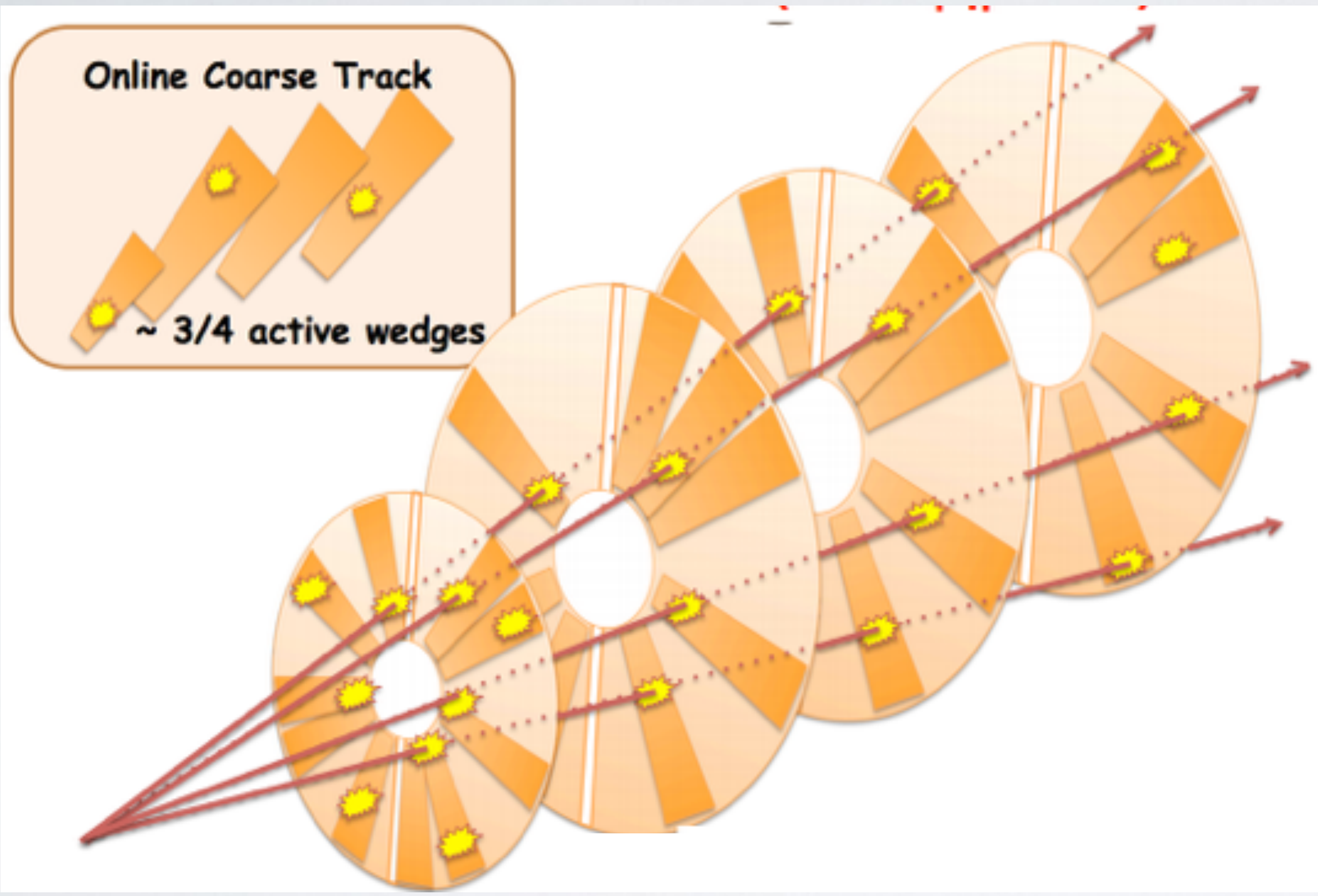




Only seen in rare ultra high multiplicity events

Slide from Wei Lei, Rice University

PHENIX HIGH MULTIPLICITY P+P TRIGGER



N_{trk}^{FVTX} $(1.2 < |\eta| < 2.2) \geq 12$

PHENIX has taken 350 Million of the rare **high multiplicity p+p** events this year using a new FVTX based trigger.

~1500 rejection power in conjunction with BBC

We are excited to try to observe the p+p ridge that CMS sees at lower energy!

CALCULATIONS OF COLLECTIVITY

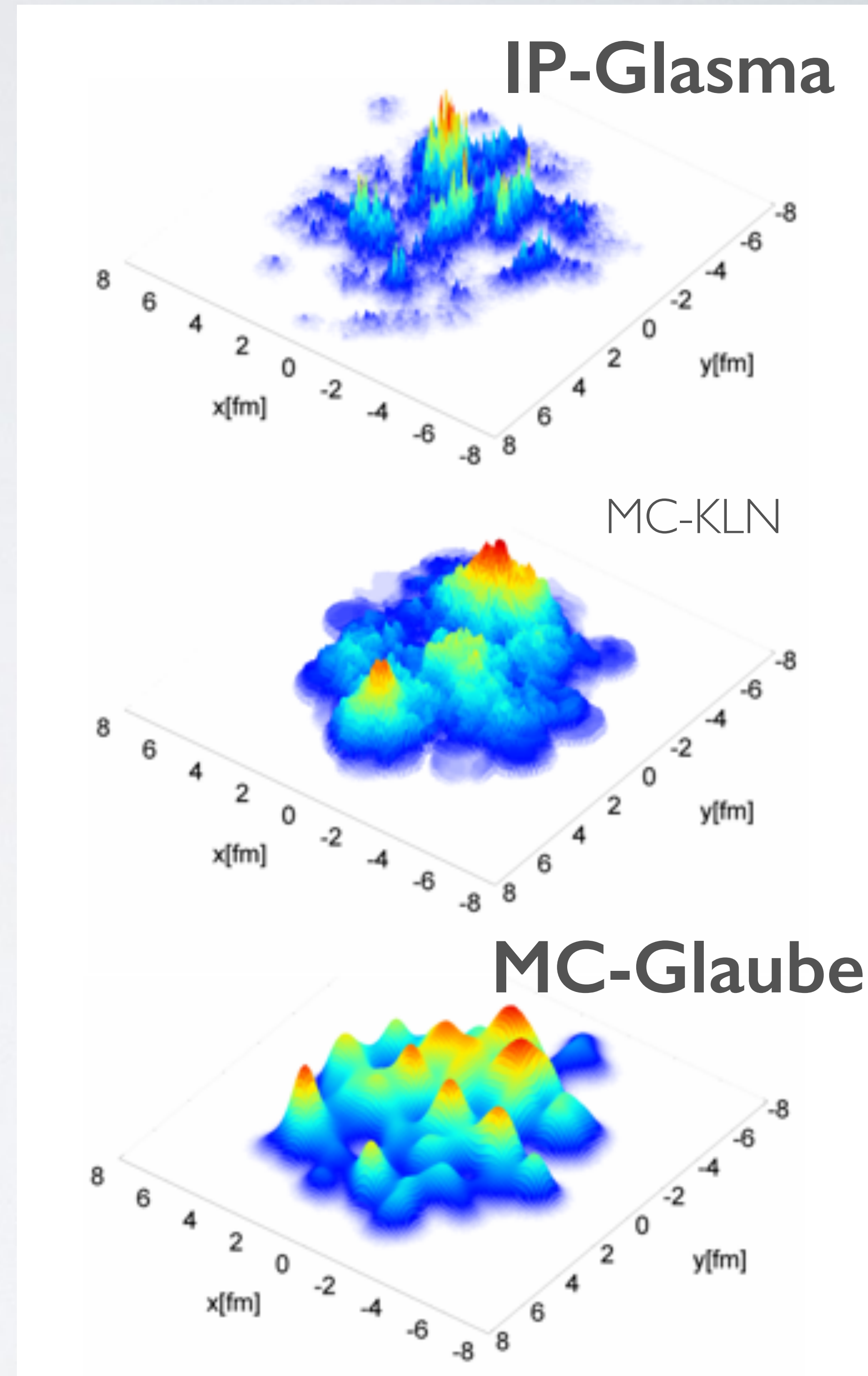
- Initial Conditions Models:
  - **IP-Glasma** (based on CGC)
  - **MC-Glauber** (tunable to data)

- Medium Evolution:
  - **Second Order Relativistic Hydrodynamics** with tunable viscosity: $\eta / s \sim 1$

  - **AMPT** (a multi-phase transport model) string-melting with tunable parton scattering cross section: σ_B

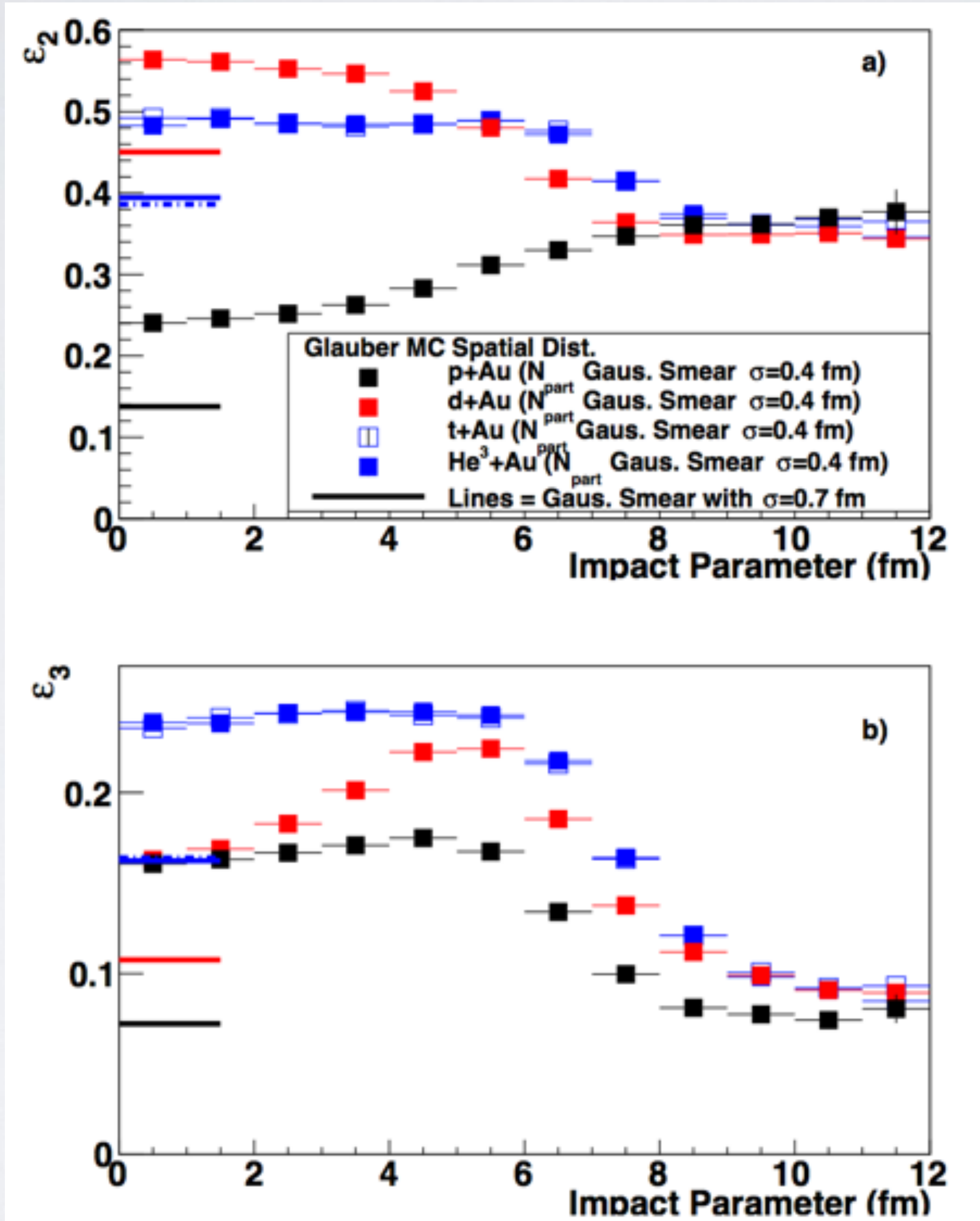
- Kinetic freeze out:
  Tunable Temperature

- **SuperSONIC** uses **MC-Glauber**, relativistic viscous **hydro** as well as pre-equilibrium flow and hadronic cascade afterburner



arXiv:1202.6646

COMPARISON BETWEEN SYSTEMS



arXiv:1312.4565v2

d+Au and **^{3}He+Au**

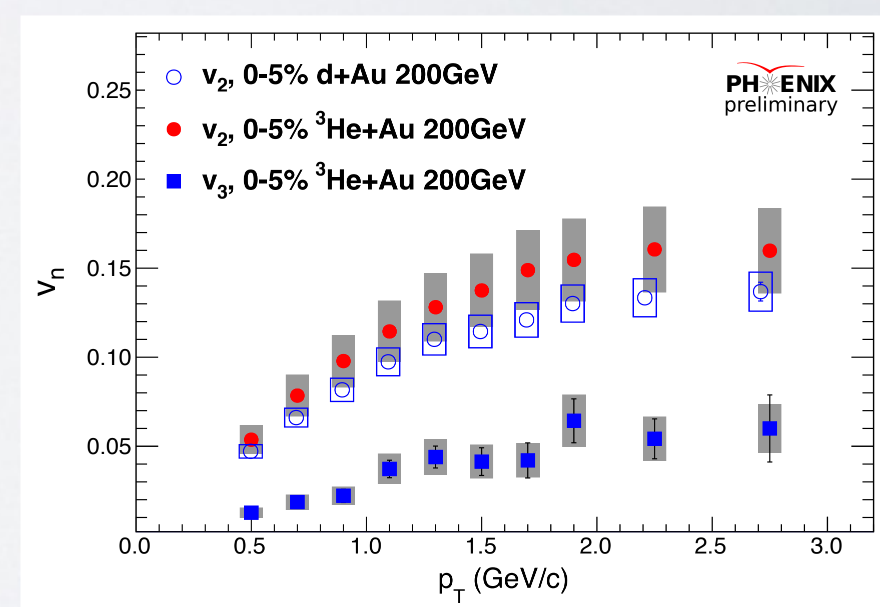
v_2 ~ same magnitude

v_2 p+Au << v_2

3He/d+Au

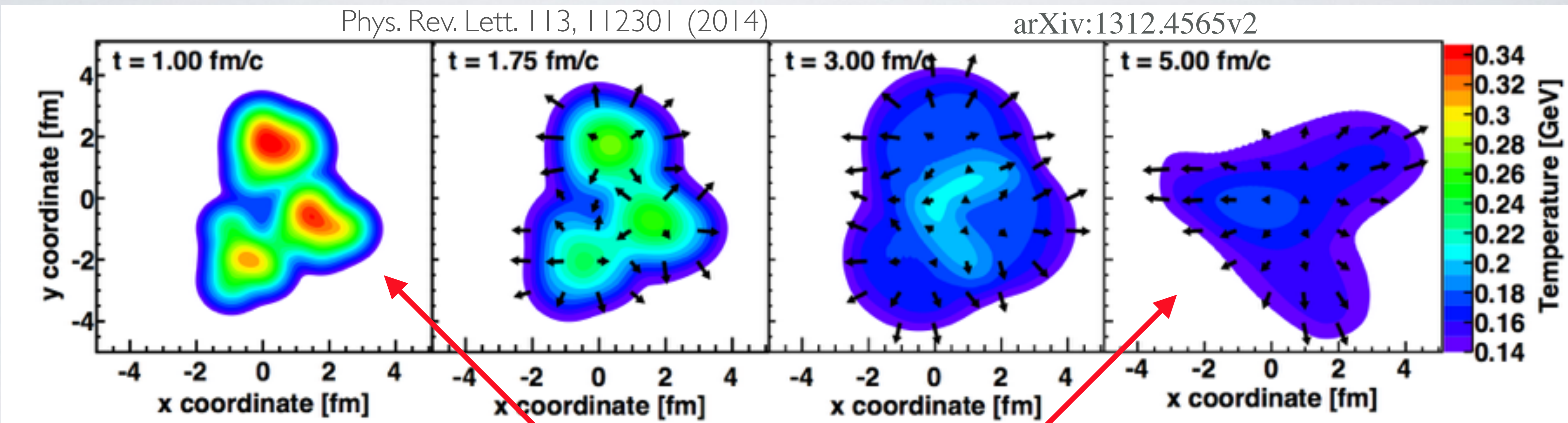
d+Au v_3 < ^{3}He+Au v_3

$\varepsilon_N =$ initial eccentricity of the collision



UNDERSTANDING THE ^{3}HE+AU MEASUREMENTS

3 Hot Spots

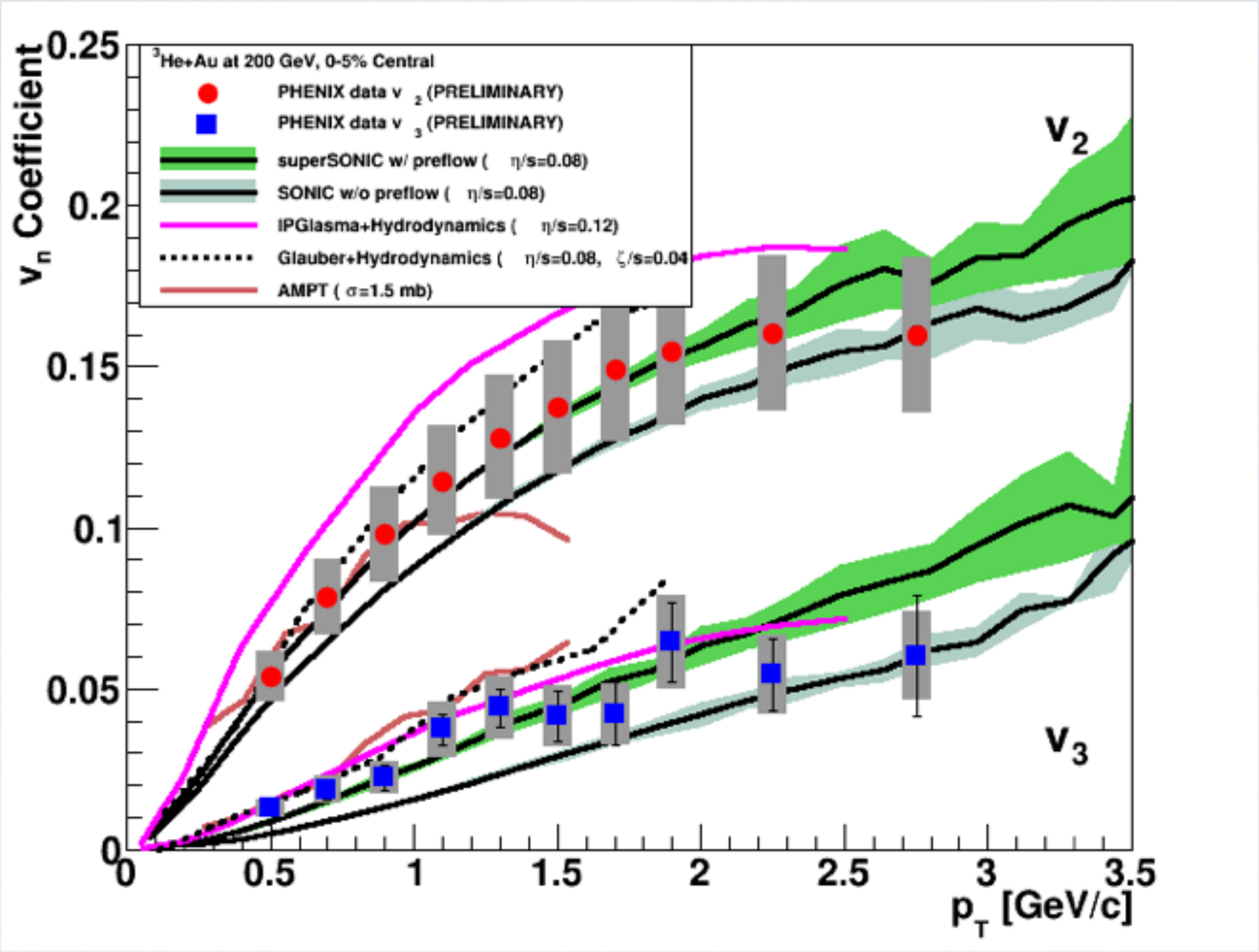


Inverted triangle

Example ^{3}**He+Au** event using **Glauber** + **Hydro**

Cooper-Frye Hadronic Cascade Temperature: $T_F = 170\, MeV$

SUMMARY OF CALCULATIONS



^{3}He+Au ***v_2*** and ***v_3*** is not enough to distinguish between these models alone, need more control experiments.

SUMMARY

- The idea that small systems collisions are the control test is a faulty assumption in the most high multiplicity events.
- There is **evidence of collectivity** in small systems.
  Now the question is **how small**?
- In the future for PHENIX:
  - Looking for the ridge in High Multiplicity triggered **p+p** events.
  - Look for azimuthal anisotropy in **p+Au** events (being taken now) with high multiplicity trigger.
  - Finding the pseudorapditiy dependence of flow for **^{3}He+Au** using the **VTX** ($|\eta| < 1.5$). Naive assumption: asymmetric collision systems should have pseudorapditiy dependence.

Questions?